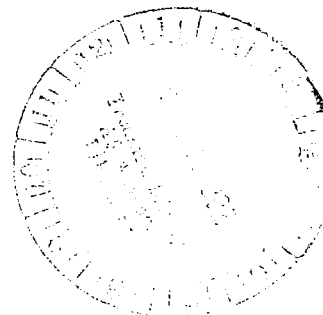


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Correlation of Satellite Lightning Observations With Ground-Based Lightning Experiments in Florida, Texas, and Oklahoma

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Correlation of Satellite Lightning Observations With Ground-Based Lightning Experiments in Florida, Texas, and Oklahoma

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Introduction

In the summer of 1977 the Piggy Back Experiment (PBE-2) lightning detector became operational with the launching of the Defense Meteorology Satellite Program (DMSP) Block 5D flight 2 satellite into a dawn-dusk sun synchronous orbit. At the same time period the Thunderstorm Research International Program (TRIP-77) was active about the Cape Kennedy area. One experiment, a long baseline lightning location system operated by Professor Uman of the University of Florida, had a wide coverage area on the order of several hundred kilometers in radius. It was thought at the time that it would be relatively simple to have the lightning location system take data while the satellite flew by overhead, and then at some later date the experimenters could compare data. In actual fact the coordination of such cooperative experiments turned out to be easier said than done.

The essential objective of these satellite-ground coordinations is ground-truth. That is, can we match the ground lightning observations with those triggers observed by the satellite? These ground-truth coordinations are governed by three independent factors: (1) satellite experiment operation, (2) ground experiment operation, (3) lightning activity. If we assign probabilities of 0.7 to the first two variables and 0.5 to lightning activity, we obtain a probability of 0.25 for success of the ground-truth coordination. Although the individual probabilities are reasonable estimates, the 25% successful coordination figure is very realistic over a campaign season.

Data Base

We will be using three data bases for our correlation of satellite and ground lightning observations. They are:

- (1) SESAME 1979 (Okla.)
- (2) TAMPA 1979 (Fla.)
- (3) Bureau of Mines Field Test 1979 (Fla. and Tex.)

The first data base, the Severe Environmental Storms and Mesoscale Experiment (SESAME), used a lightning location network based at the Severe Storms Lab in Norman, Oklahoma and operated for the months of April and May 1979. The second data base utilized the lightning location network of Tampa Power and Light during the months of July and August 1979. The third data base used data collected by Dr. Johnson of Southwest Research Institute during field trials of various lightning detection devices for the Bureau of Mines (BOM). Our data base used data collected at Cape Kennedy and San Antonio, Texas. A third location at Socorro, New Mexico was not used as a data base because the lightning activity occurred at midday and not when the satellite passed over. All of the lightning location systems were manufactured by Lightning Location and Protection, Inc. (LLP) and detected only negative cloud to ground (CG) lightning flashes.

The Satellite Experiment

The PBE-2 lightning detector was carried aboard the DMSP Block 5D F-2 spacecraft, launched in July 1977. Initially the spacecraft was placed in a dawn-dusk orbit (5 am-6 pm), but the orbit was drifted to the point such that in 1979 the orbit was at 9 am-9 pm local time. This fact had considerable impact on the data collected. In Florida the local diurnal peak in thunderstorm activity is generally in the late afternoon. At 9 pm the satellite sees very sparse lightning activity over the land, because the lightning cells have moved out over the water, usually into the Gulf of Mexico or along the Gulf Stream. However, in Oklahoma the 9 pm orbit does place the satellite at a

time when severe local storms do occur, and as a consequence some of the highest lightning occurrence rates were observed during SESAME 1979. Generally for all locales studied there was a lull in lightning activity at 9 am so no ground-truth was obtained for morning passes.

The DMSP satellite sun synchronous orbit spaces the equatorial crossing points at every 25° of longitude. This orbit period is such that the earth rotates 25° and the satellite crosses the equator at the same local time as the previous orbit. However, the spacing is not quite exact which produces a drift of about 5° longitude per day. In setting up ground-satellite coordination times, our experience shows that the satellite passes usually over a ground site 1-2 days out of 5 days shown in Figure 1.

The satellite lightning experiment consists of a silicon photodiode detector which tracks in time a rapidly rising lightning pulse. The data output consists of the amplitude of waveform sampled every 32 msec. The threshold is 10^9 watts source power. In the PBE-2 instrument, one data frame is outputted every 4 seconds, and an onboard 32 frame memory handles incoming lightning pulses which are received at rates greater than one event every 4 sec. An event counter keeps track of how many triggers arrive in any 4 second time bin. With this information, the triggers which are stored in memory can be assigned to the actual 4 second bin in which the instrument observed it. However, we are limited to a timing resolution of 4 second/bin. (This drawback was corrected with the PBE-3 detector, but we do not have ground-truth data for it.) An elapse time counter is able to count up to 130 msec. intervals between triggers in a 4 second bin. This information allows us to link triggers in a bin to be part of one flash if the elapse time is 30-130 msec, but if it is greater than 130 msec, we assume the events are separate flashes.

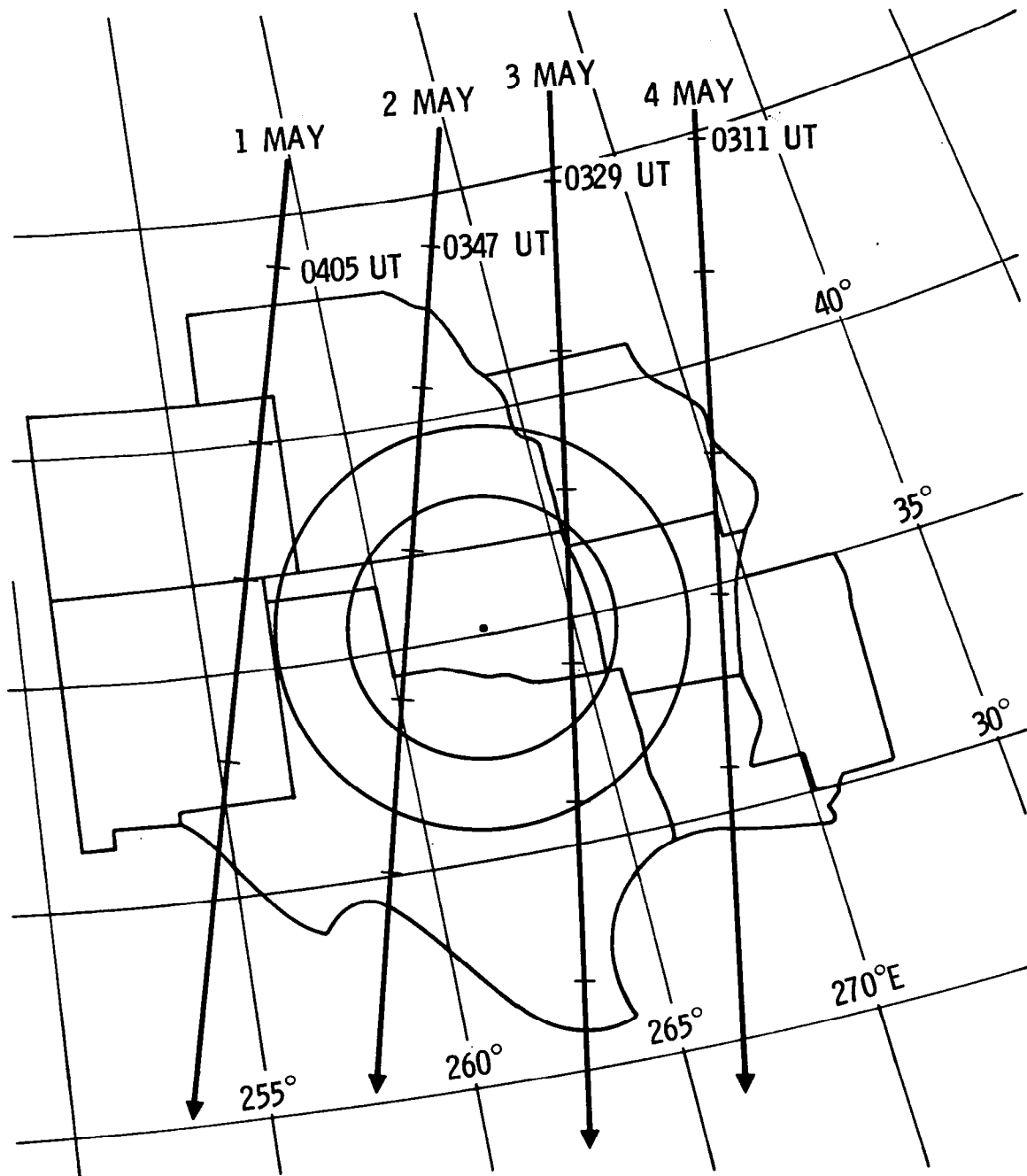


Figure 1. Typical Pass Sequence for May 1-4, 1979 Over the SESAME Area. The May 2nd and 3rd passes observed good lightning activity which correlated with ground data.

The main field of view (FOV) of the instrument covers a circular area of 570 km radius at which point the response falls off in a linear response at a radius of 680 km. A schematic of the FOV is shown in Figure 2. The total area is approximately 1.2×10^6 km². The large FOV does cause some problems with ground-truth observations. A typical two station lightning location network has a range of 300-500 km. On an overhead pass the satellite may see the same lightning cell that the ground station sees, but another cell out of the ground station's range but in the satellite FOV will introduce additional triggers which do not correlate with the ground station records. In some cases the percentage of uncorrelated satellite triggers may be 50% of the total number of events in an overhead satellite pass. The multiple cell case is a source of uncertainty in sorting out satellite and ground records.

SESAME 1979

We will begin our data analysis with three case studies for passes occurring on April 10, May 1, and May 2, 1979 (CST).

April 10, 1979

This data is most notable for the tornado outbreak that happened primarily from 1500 to 2000 CST. The satellite came overhead at 2115 CST when there was still significant lightning activity in the SESAME area. Figure 3 shows the satellite track passing to the east of the cloud complex. (The cloud boundary at 1700 CST is also outlined on the map.) The dots along the track denote the satellite position when a trigger was observed. A line connects the subsatellite position to the ground flash location that correlated with the satellite event.

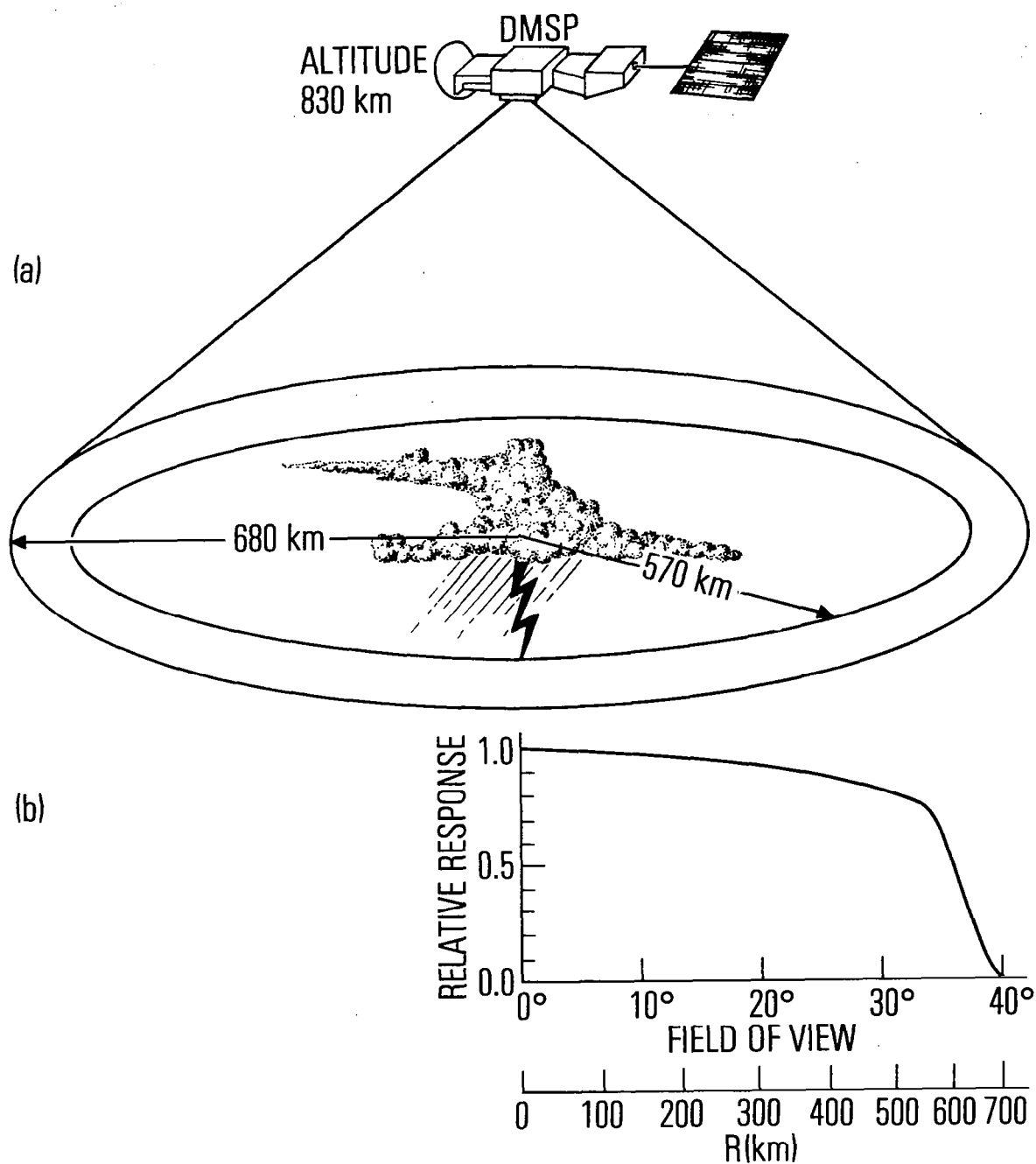


Figure 2. (a) Schematic of the FOV of the DMSP Lightning Sensor Showing the Primary and Secondary FOV's. (b) Relative Response of the Sensor as a Function of Range from Subsatellite Point.

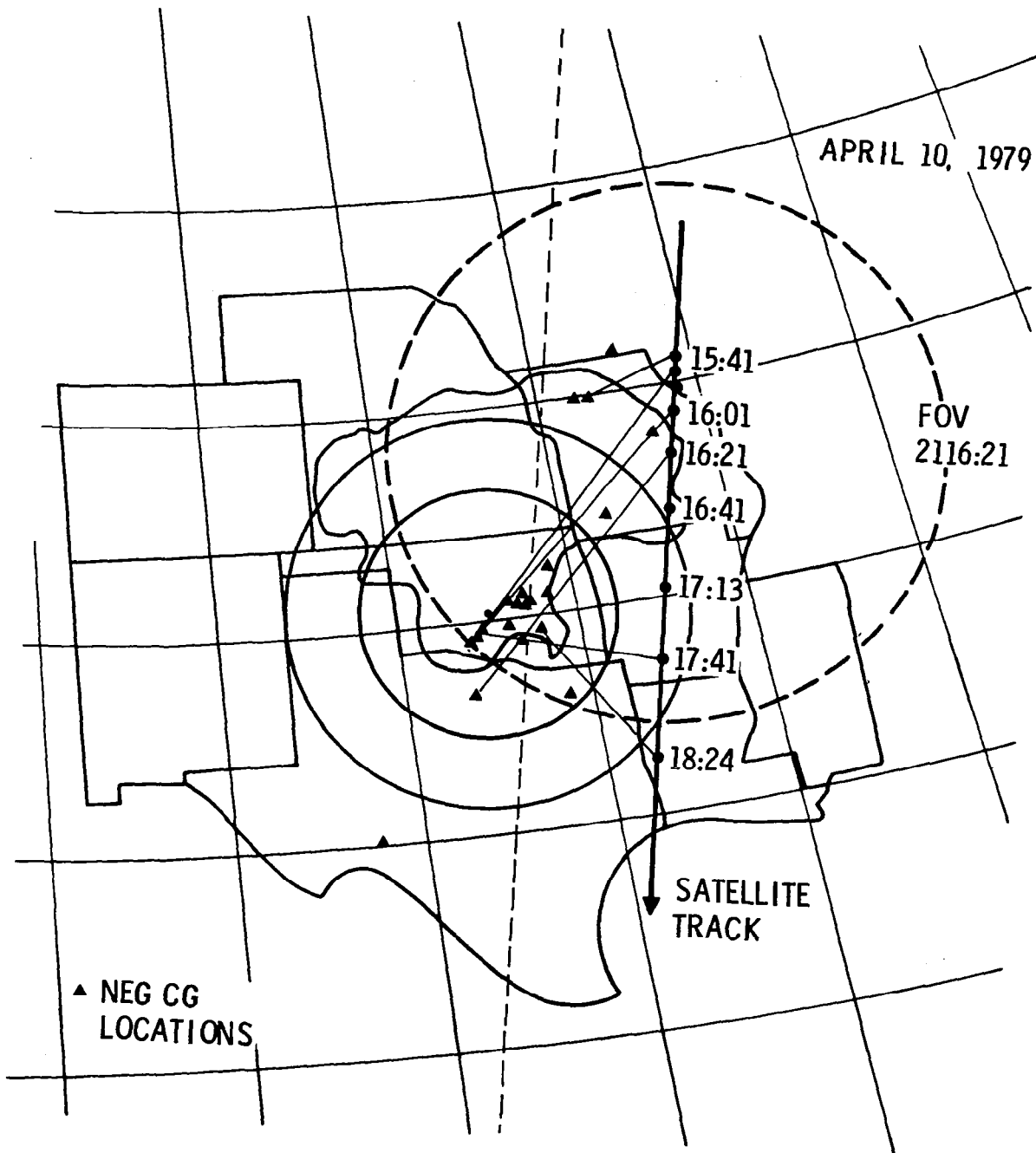


Figure 3. Ground-Truth for April 10, 1979 Showing the Satellite Track and the Correlation of Satellite Trigger Times and Positions with the Ground Positions of Negative CG's

The time correlation is shown in Figure 4. The ground record is grouped into 4 second bins to correspond with the satellite record. The correlation percentage, based upon the time comparison, is 20%. However, because there may be a time offset between the satellite clock and the ground clock, we performed a time offset correlation. The results are given by Figure 5. A negative offset means that the ground clock is behind the satellite clock. A positive offset means that the ground clock is ahead of the satellite clock. Generally because the operator manually sets the ground clock, a negative offset results. A several hundred msec negative offset does increase the correlation to 23.5%, although a +500 msec offset also achieves the same result. The improvement of the correlation results from the negative offset because the two satellite events at 2117:41 can now correlate with the events in the 2117:37 and 2117:41 bins.

Several ground events that correlate well in time actually lie outside of the FOV, e.g. 2116:21 in Figure 3. However, because the time correlation is good, we believe that light scattering by the cloud allows the sensor to observe the flash.

May 1, 1979

The May 1st pass observed a lightning activity area centered on the Oklahoma - Kansas border as shown in Figure 6. A time correlation (Figure 7) gave a 20% correlation with seven uncorrelated satellite triggers. A -1 second offset improves the correlation to 25%. In our previous Florida lightning studies we had seen a trend whereby the uncorrelated satellite triggers tended to have longer durations than the correlated ones. The following table compares the durations for the correlated and uncorrelated triggers.

2115: (CST) 2116: 2117:

41	49	57	05	13	21	29	37	45	53	01	
1	0	1	0	0	1	1	0	0	1	1	0
2	1	0	2	0	0	3	0	0			
											GND
1	1	0	0	0	1	0	0	0	0	1	0
0	0	0	0	0	0	2	0	0	0	0	0
											SAT
C NC			C		C		CC				

2117: 2118:

01	09	17	25	33	41	49	57	05	13	21	
1	2	0	1	2	2	0	0	1	1	0	1
1	2	0	1	1	2	0	1	1	0	1	1
											GND
0	0	1	0	0	0	0	0	0	2	0	0
0	0	0	0	0	0	0	0	0	0	0	0
											SAT
NC			C						C		

Figure 4. Time Line Correlation between the Satellite Record and Ground Record as Arranged into 4 Sec Bins with No Time Offset for April 10

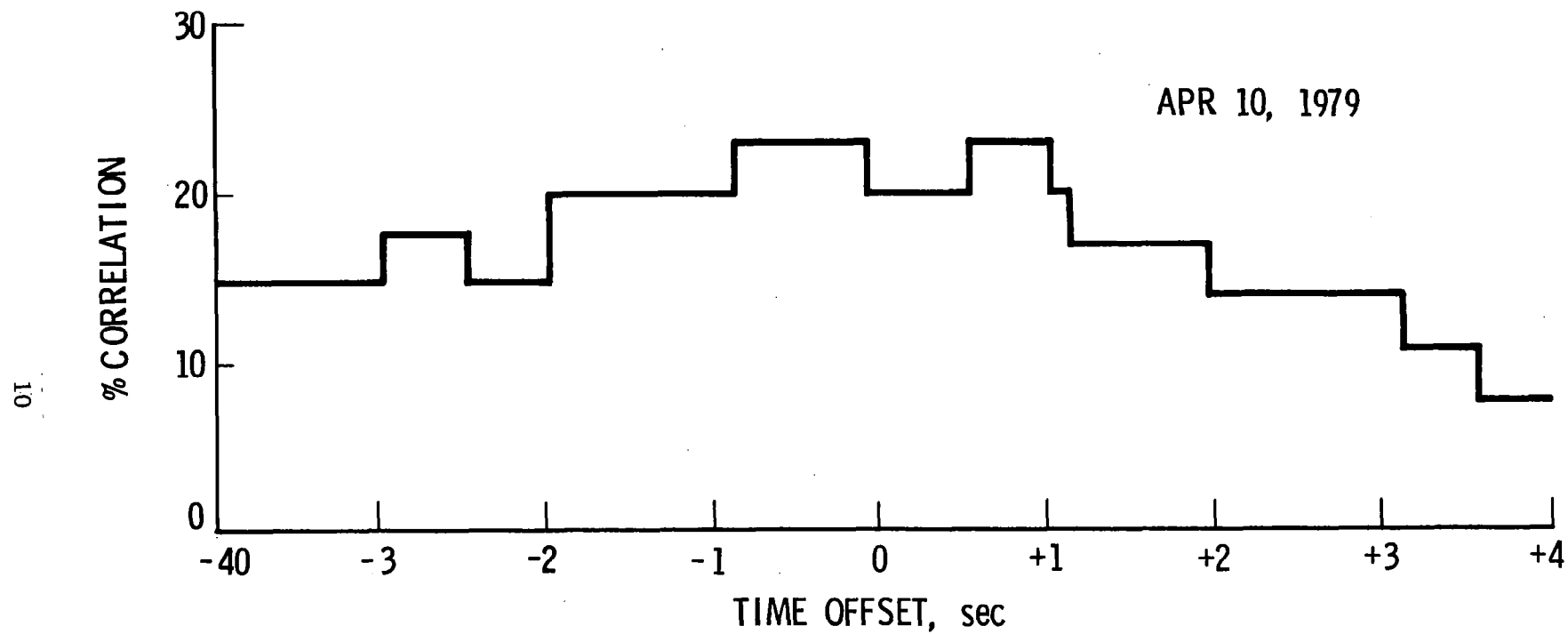


Figure 5. Time Offset Correlation for April 10, 1979. The maximum correlation occurs for offsets of less than 1 second.

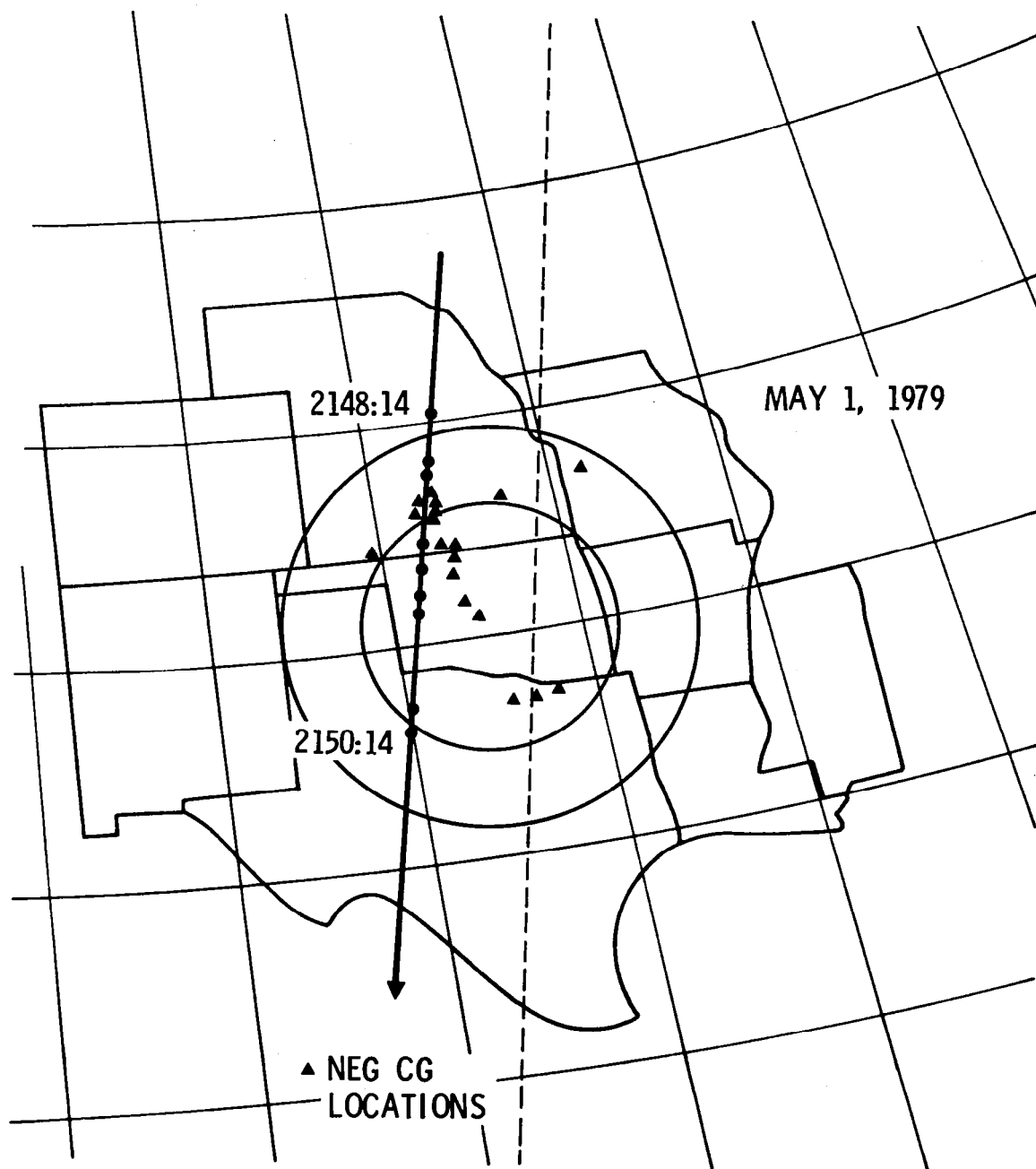


Figure 6. Ground-Truth Test for May 1, 1979. The satellite passed directly over the storm which straddled the Oklahoma-Kansas border.

ZERO OFFSET

CST

2148:

2149:

2150:

10 18 26 34 42 50 58 06 14 22 30 38 46 54 02 10 18

0 0 0 2 0 1 0 0 0 1 1 0 0 0 1 0 1 2 0 0 1 1 1 0 1 0 1 1 2 0 1 1 1 GND

(a)

0 2 0 0 0 1 1 0 0 0 0 0 0 0 1 1 0 0 1 1 1 0 0 0 0 0 0 0 0 1 0 1 0 SAT

NC

C NC

C NC

NC NC C

NC C

4 / 20 20% CORR

-1 sec OFFSET

2148:

2149:

2150:

9 17 25 33 41 49 57 05 13 21 28 37 45 53 01 09 17

0 0 0 2 0 1 0 0 0 1 1 0 0 0 0 1 1 2 0 0 1 1 1 0 1 0 0 1 1 1 1 1 1 GND

(b)

0 2 0 0 0 1 1 0 0 0 0 0 0 0 0 1 1 0 0 1 1 1 0 0 0 0 0 0 0 0 1 0 1 0 SAT

NC

C NC

NC C

NC NC C

C C

5 / 20 = 25% CORR

Figure 7. (a) Time Line Correlation for May 1, 1979 with No Time Offset.

(b) Time Line Correlation for May 1, 1979 with a -1 Sec Offset.

The correlation improves by 5%.

<u>Correlated</u>	<u>Non-Correlated</u>
0.42 msec.	0.96 msec.
0.29	0.48
0.29	0.48
0.32	0.48
<u>0.32</u>	0.35
	0.42
0.33 - Avg.	<u>0.93</u>
	0.59 - Avg.

Certainly, there is the same trend that on average the uncorrelated satellite triggers are longer in duration than the correlated triggers. The uncorrelated triggers are probably a mixture of positive and cloud flashes.

May 2, 1979

This pass saw the highest occurrence rate of lightning flashes ever observed in the mid-western U.S. by the PBE-2 sensor. Figure 8 shows that the satellite passed over a squall line of intense activity. The two circles denote the FOV as the satellite first observed the activity and the FOV as the satellite stopped reporting activity. The overlap of the two FOV's neatly enclosed the active area.

Figure 9 shows the time line correlation. Nineteen of the satellite triggers correlated with the ground events giving a correlation of $19/74 = 26\%$. A timing offset correlation showed little variation of the correlation percentage because of the high number of ground events. For this reason we believe that there are a few false correlations. When the duration statistics are separated into correlated and non-correlated triggers we find that the trend is just the opposite of that for May 1st.

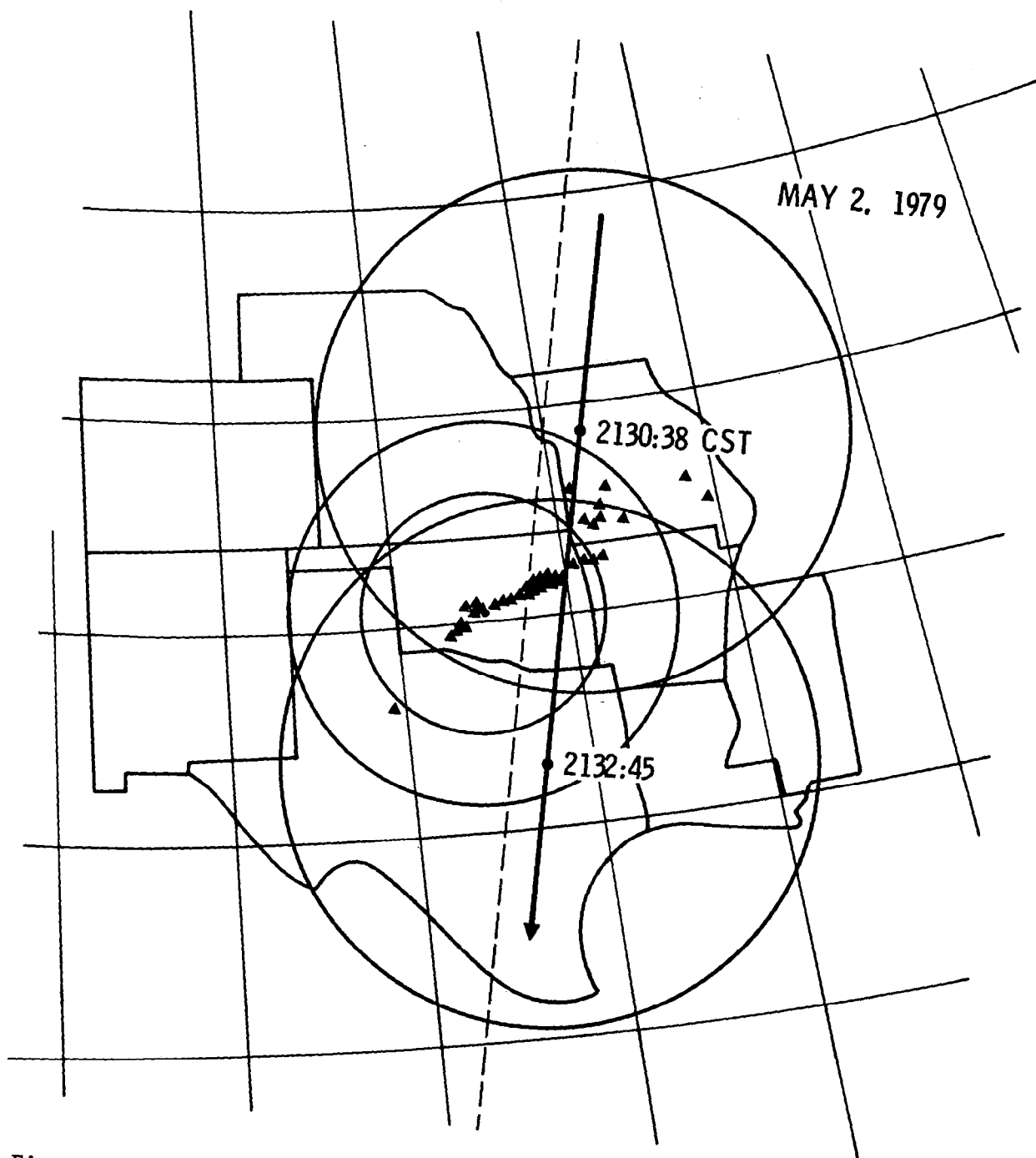


Figure 8. Ground-Truth Test for May 2, 1979. The satellite passed over a squall line which ran diagonally across Oklahoma.

ZERO OFFSET

CST

2130:

2131:

2132:

33	41	49	57	05	13	21	29	37	45	53	01	09	17	25	33	41																		
2	3	3	3	2	4	2	3	1	3	2	0	0	2	3	5	1	2	5	1	2	1	0	3	4	1	1	2	0	2	1	4	5	1	GND
0	1	1	2	0	0	4	2	2	1	1	1	1	1	0	1	0	0	1	1	1	0	0	0	0	1	0	0	1	0	2	0	1	0	SAT
C C C			C C C C C			C N C N C C			C			C C C			C			NC			C		C											
C			C C																															

$$19 / 74 = 26\% \text{ CORR}$$

Figure 9. Time Line Correlation for May 2, 1979 with Zero Timing Offset

May 2nd Durations

<u>Correlated</u>	<u>Non-Correlated</u>
1.0 ms	0.5
0.5	0.5
0.3	0.5
0.5	<u>0.5</u>
0.5	0.5 msec - Avg.
0.4	
1.5	
1.3	
0.3	
<u>0.8</u>	
0.68 msec - Avg.	

For this comparison we chose satellite events for which there was a unambiguous correlation or non-correlation with the ground record. So it appears for some passes there appears to be a correlation between negative flashes observed on the ground and the short duration satellite triggers. But for other passes it may not be obvious that there is a correlation between flash polarity and optical signal duration.

Correlation Statistics

The following table summarizes the results of all the successful satellite - ground coordination for SESAME 1979. The success rate for both the satellite and ground systems being operational was 4/20 or 20% which is close to our original estimate in the introduction.

<u>Date (CST)</u>	<u># GND Flashes</u>	<u># SAT Triggers</u>	<u>Correlation</u>	<u># SAT No Correlation</u>
9 Apr	8	6	4/8 50%	2
10 Apr	36	10	8/36 22%	2
1 May	20	12	5/20 25%	7
2 May	74	25	19/74 26%	6

There were several passes where the satellite saw activity just outside of the range of the ground station and vice versa, but we found no passes where the satellite passed over an active storm cell and did not record any events.

Threshold Analysis

It was thought that if we introduced an artificial threshold into the ground data when we did the satellite correlation, we might correlate the known optical threshold of 10^9 watts with an electric field threshold on the ground. However this hypothesis assumes a constant threshold over a wide range for the ground station. Figure 10 shows the median E-field as a function of range. This figure implies that the ground threshold only remains constant over the first hundred km and increases for ranges greater than 100 km. The average E-field range for the three case studies is about 10-12 V/m which corresponds to an average range of 150 km. This range is typical of the correlated events.

Figure 11 plots the percent change in correlated events to uncorrelated events as the ground threshold is artificially raised. For the two passes that passed directly over a storm cell (1, 2 May), there is a sharp shift in

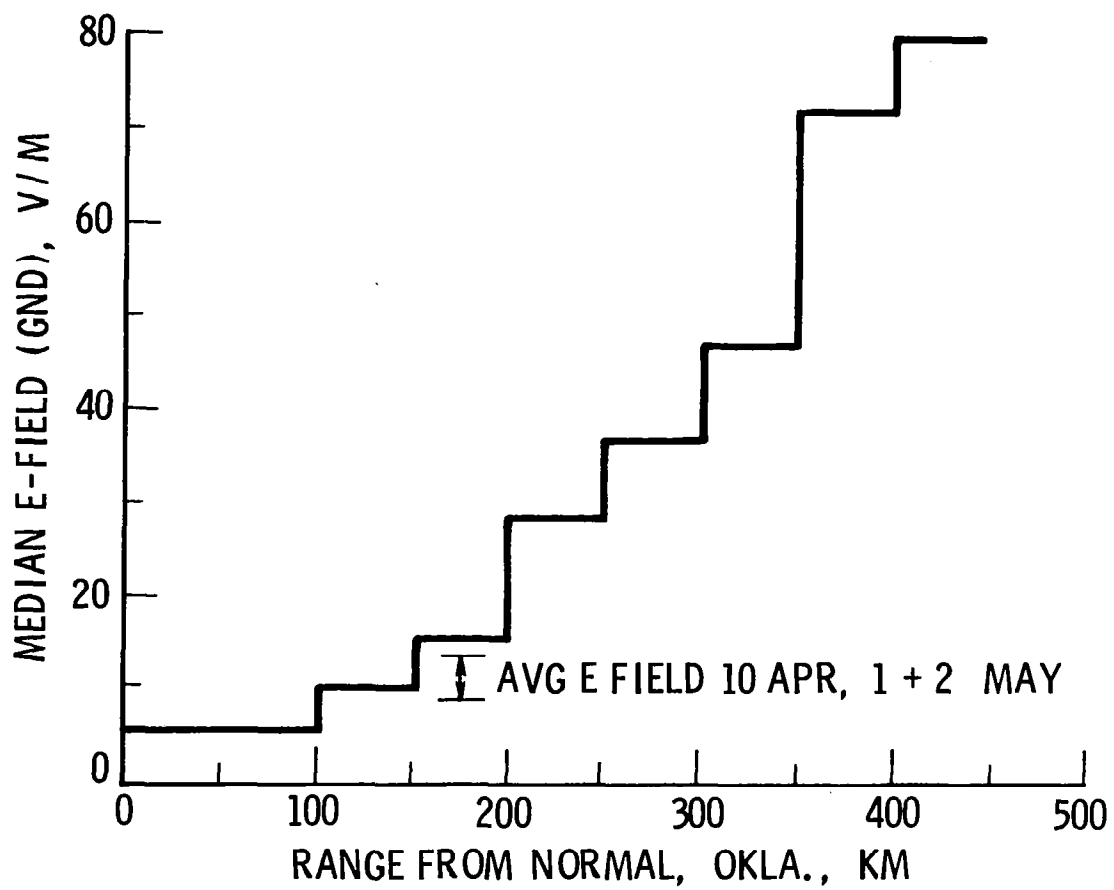


Figure 10. Median Received E-Field versus Range for the Oklahoma Lightning Location Network 1979

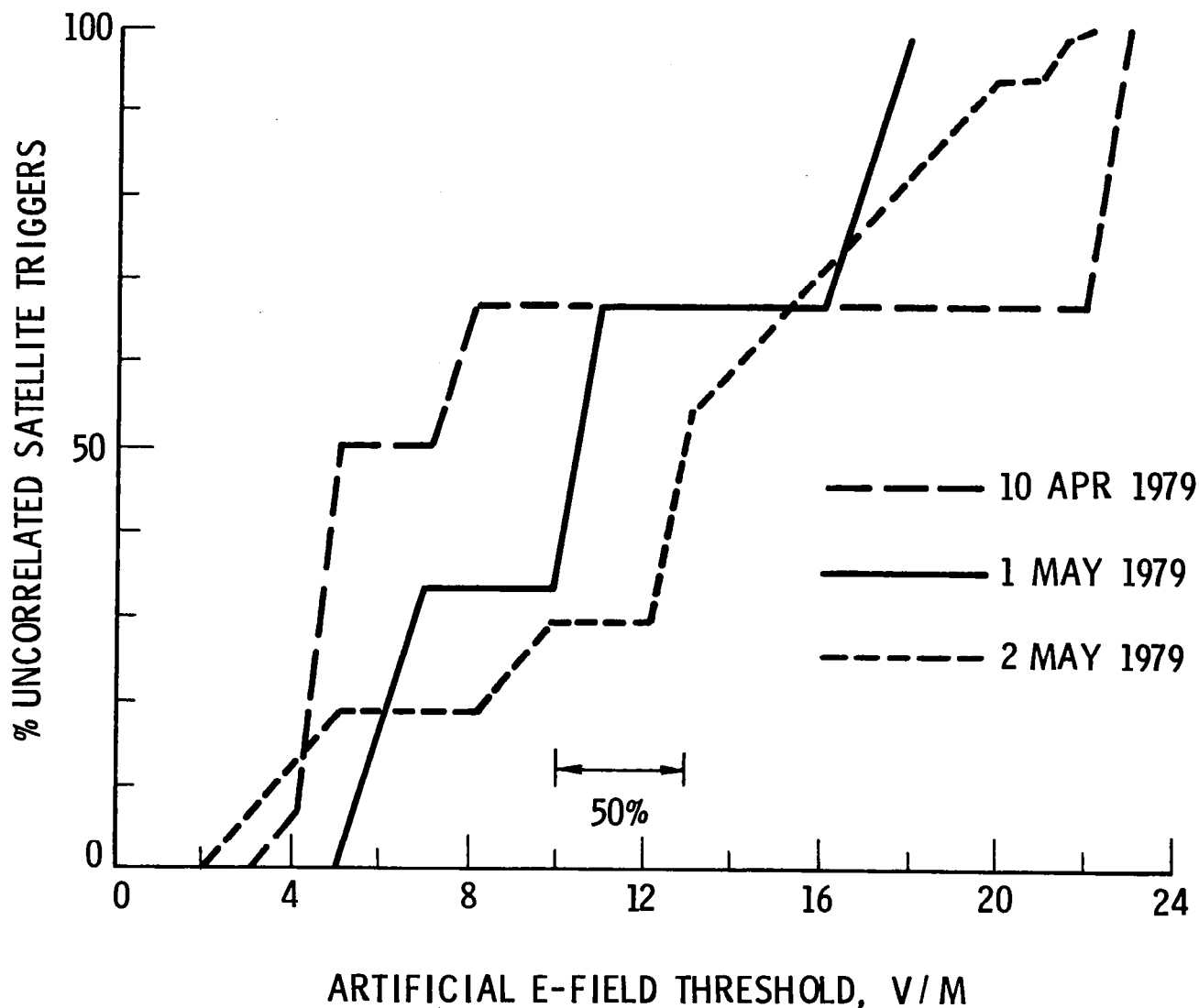


Figure 11. Non-Correlation versus E-Field Threshold for April 10, May 1, and May 2 Ground-Truth Tests. This graph shows the percent change in noncorrelated satellite events as an artificial E-field threshold is introduced into the ground data. For May 1 and 2, there is a 50% loss of correlated satellite events for a 10-13 V/m threshold. For April 10th the 50% change occurs at 5-7 V/m.

the percent of uncorrelated events at 10-13 V/m. For a pass off to the side of a storm cell and at a long range from the satellite, the rapid shift is at a lower electric field (5 V/m). Because of the variable ground threshold at large range values and optical attenuation problems, we can only state that it appears that the satellite threshold corresponds to about 10 V/m.

Flash Density

For April - May 1979 we have very good flash density numbers for Oklahoma as shown in Figure 12 (courtesy of Mike Maier). The units are in Flashes/km² - 2 months. Averaging the contours gives a flash (neg.) density of 1.09. Converting this number to more ordinary time units gives 1.3×10^{-5} flashes/km²-min. The flash density from the satellite observations, calculated from 15 passes, gives a flash density of 1.11×10^{-6} flashes/km²-min. If we assume a ground detection efficiency of 0.8 and ratio of negative CG's to total flashes of 0.44 (courtesy of D. Rust), we arrive at a total flash rate of 3.6×10^{-5} flashes/km²-min. Combining this number with the satellite flash density gives a detection efficiency of 0.03. This number fits well with previous comparisons as shown by Figure 13.

The question still remains - why do we obtain 25% correlation of the satellite observations with the ground data in view of the 3% detection efficiency? The passes for which we obtained ground-satellite correlations all had good lightning activity. Unfortunately we did not obtain ground records for satellite passes that had no activity. The flash density calculation included eight passes for which no lightning activity was observed by the satellite (and also no ground records existed). So the flash density calculation is a much more realistic figure over the SESAME period in 1979.

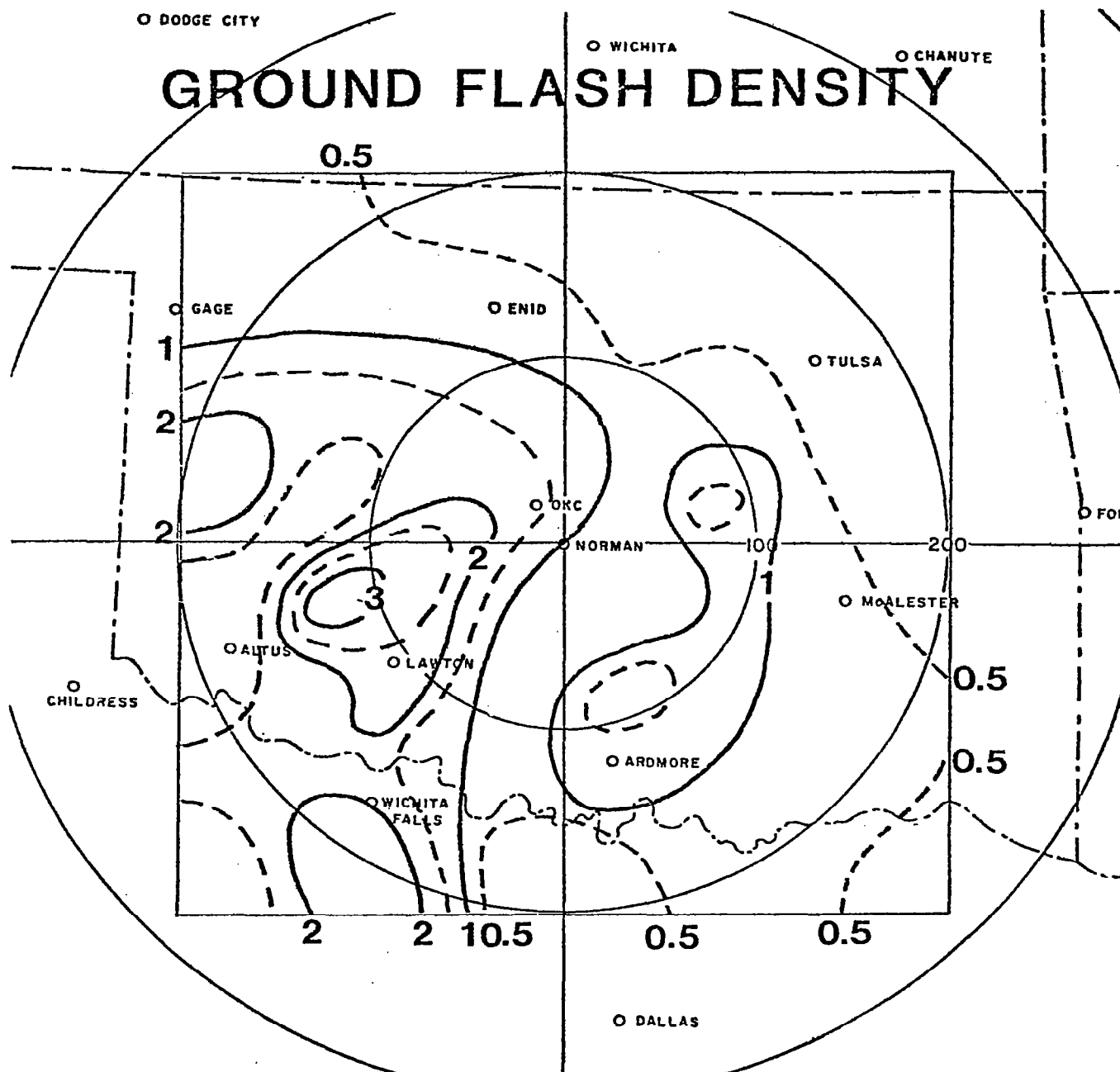


Figure 12. Ground Flash Density (Neg. CG's) for Oklahoma, 1979 in Units of Flash/km² - 2 Months. (Courtesy of M. Maier.)

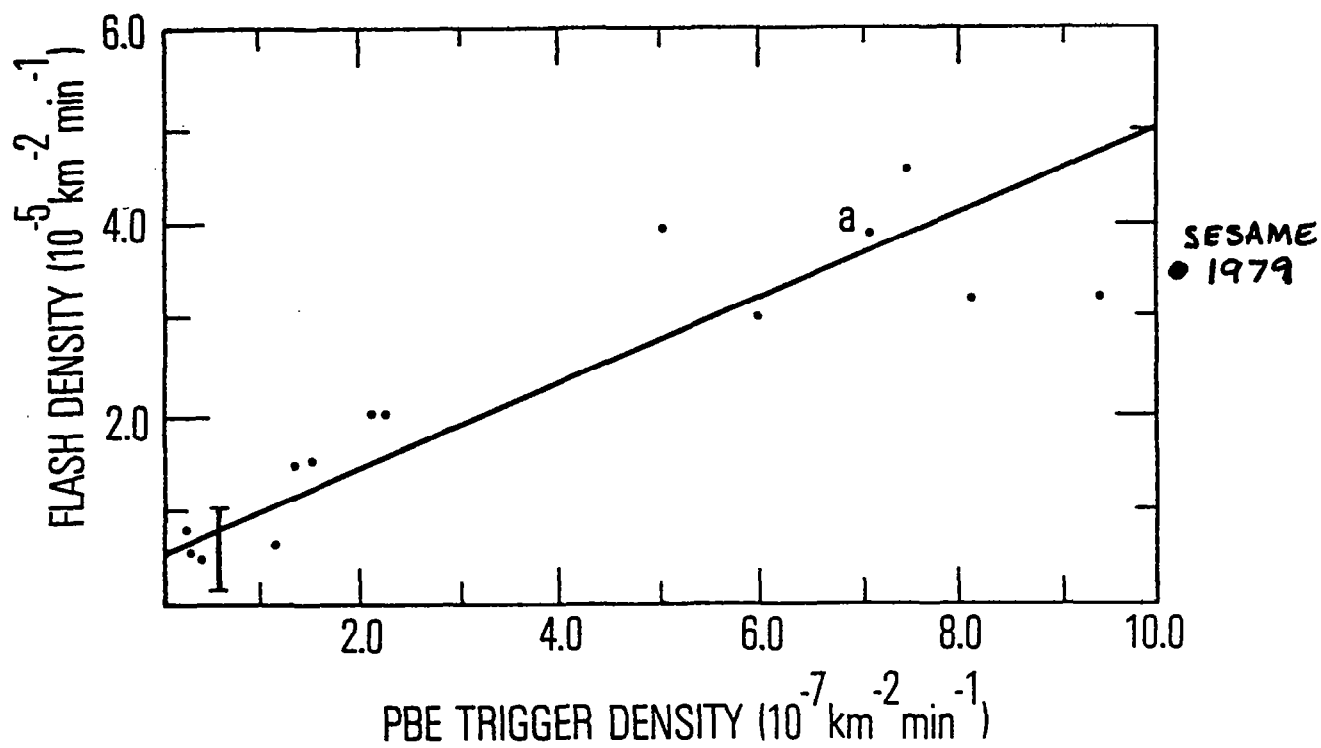


Figure 13. Correlation of Satellite Flash Density and Ground Flash Density as Determined by Turman and Edgar (1981) with the SESAME 1979 Data Point

Tampa, Florida Data

Florida storms constitute a different weather phenomenology from Oklahoma storms. Instead of synoptic scale storms (Oklahoma), in Florida we see air mass storms which tend to be isolated. These air mass storms have a strong diurnal peak at ~ 4 p.m., whereas in Oklahoma there was no definitive diurnal peak. Since the satellite pass occurs at ~ 9 p.m., it will observe only vestiges of the main activity. Krider (private communication) in a measured flash density diurnal curve for Kennedy Space Center found that at 9 p.m. the activity is down by an order of magnitude from the peak at 4 p.m.. Indeed the Tampa, Florida data base for summer 1979 counted an average of five flashes for a satellite flyby (seven passes) in contrast to an average of 35 flashes per pass for the Oklahoma data base (four passes). Also the majority of the flashes located by Tampa station were placed in the Gulf of Mexico. Very few were over the land.

Figure 14 shows a typical pass over Florida in which the Tampa Station recorded two flashes in a cell off of Florida in the Gulf of Mexico. However, the satellite lightning detector recorded seven triggers during the pass. An examination of a satellite cloud photo (Figure 15) shows that there are several other storms (between Florida and Cuba and south of Cuba) that are probably responsible for the extra triggers. The Tampa Station used a 50 mile baseline which limited its range.

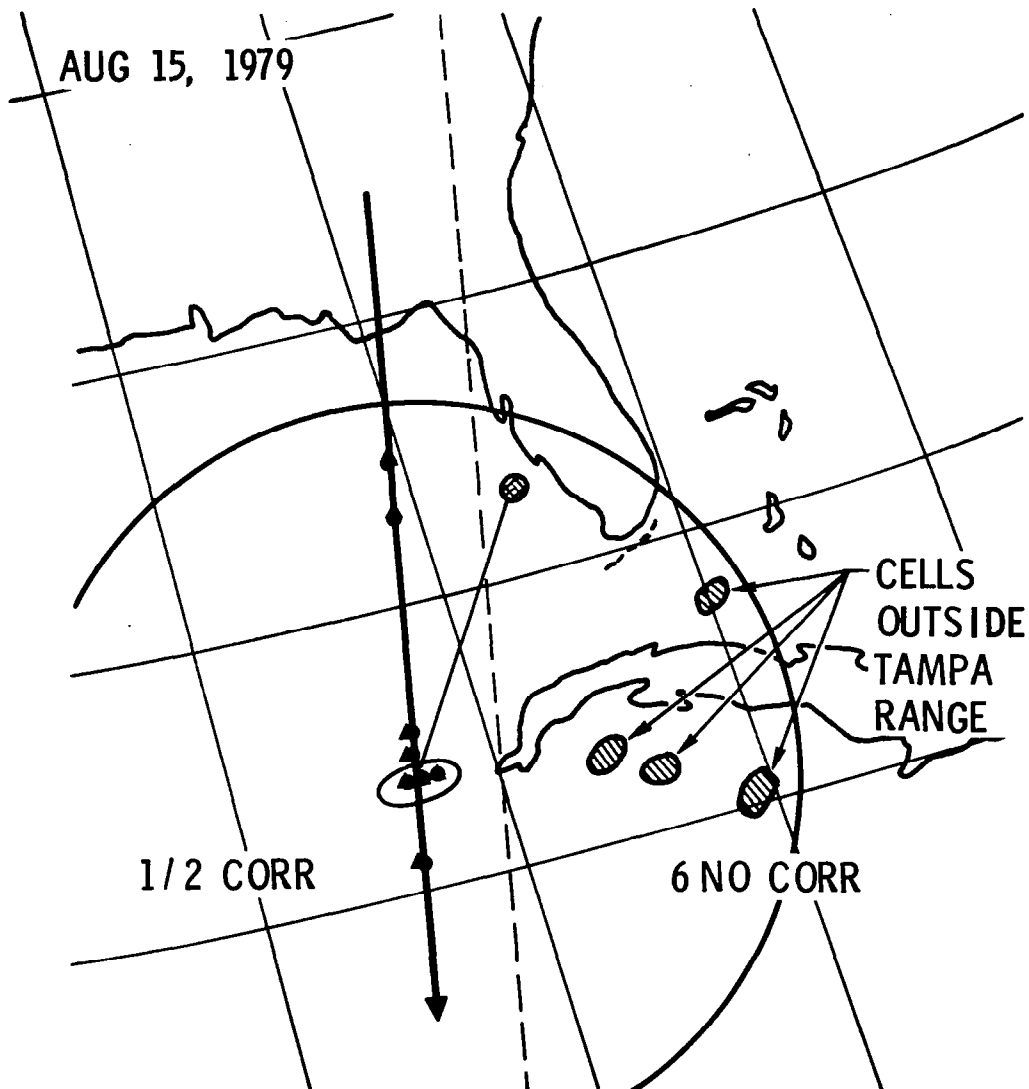


Figure 14. Ground-Truth Test for August 15, 1979 Pass Over Florida. The ground station detected a cell off of the Florida Gulf coast. However, the satellite saw many uncorrelated events which could have come from cells outside of the Tampa station's range.

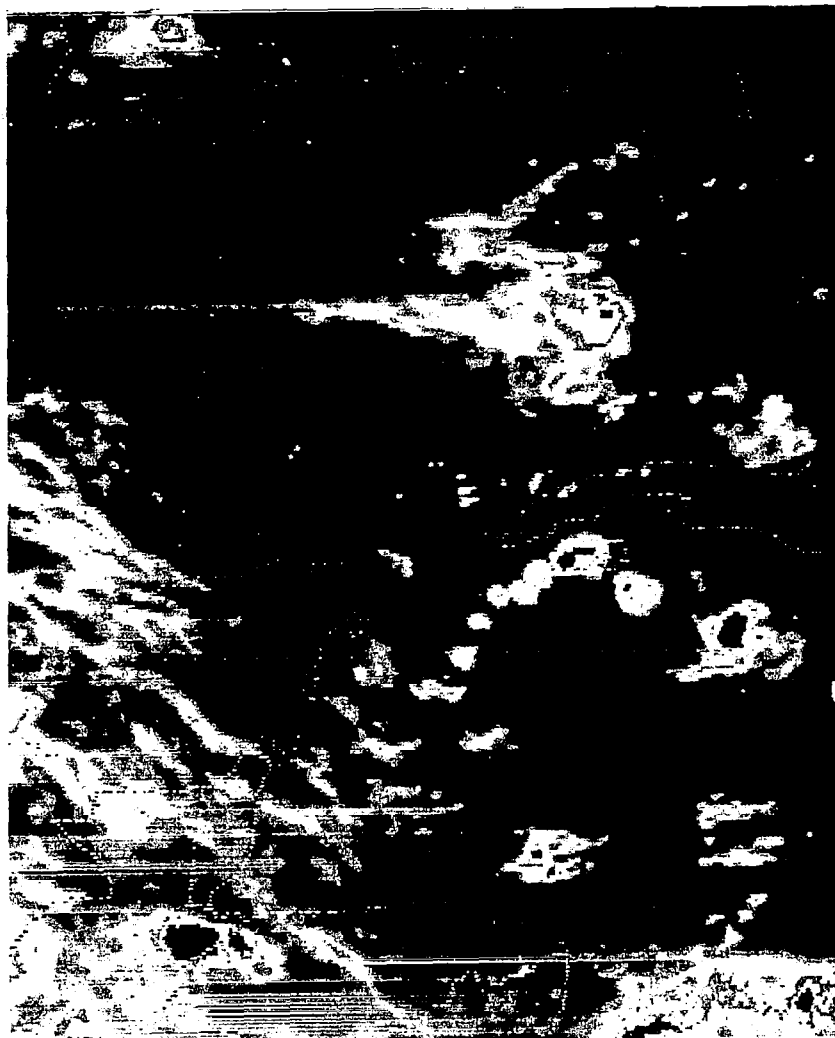


Figure 15. A GOES IR Photograph for August 15th Shows the Cell Off of the Florida Gulf Coast Along with Cells between Florida and Cuba and South of Cuba. The other cells were no doubt also active.

The following table summarizes the Tampa-Satellite coordinations:

<u>FLORIDA 1979</u>				
<u>Data (UT)</u>	<u># Gnd Flashes</u>	<u># Sat Triggers</u>	<u>% Correlation</u>	<u># Sat. Triggers No Corr.</u>
14 Jul	3	1	1/3 33%	0
18 Jul	2	10	2/2 100%	8
19 Jul	6	9	5/6 83%	4
5 Aug	8	23	4/8 50%	19
15 Aug	2	7	1/2	6
16 Aug	2	11	2/2	9
17 Aug	10	1	0/10 0%	10

The majority of the passes saw many triggers that did not correlate with the Tampa data and probably came from cells south of Florida which were out of range of the ground station. The percent correlation numbers are higher than the figures (25%) for Oklahoma storms. One might speculate that there could be false correlations due to the number of storms outside of the ground stations range. But the two ground truth passes from 1977 which used a long baseline location system gave similar results.

<u>FLORIDA 1977 (6 p.m.)</u>				
<u>Date</u>	<u># Gnd Flashes</u>	<u># Sat Triggers</u>	<u>% Correlation</u>	<u># Sat. Triggers No. Corr.</u>
6 Aug	20	14	10/20 50%	4
8 Aug	8	11	7/8 87%	4

The main reason for the higher percent of correlation is probably due to the fact that the air mass storms are isolated cells, and thus there are many optical paths available to the satellite sensor.

Florida Flash Density

Using 13 passes from July - August 1979 (this represents the total satellite data set for the period) we arrive at a flash density of 2×10^{-6} flashes/km²-min. However this number is representative of the Florida, Gulf, and Caribbean areas which encompass a much larger area than the Tampa station coverage. A typical flash density for KSC at 9 p.m. as measured by Krider is 5×10^{-5} flashes/km²-min which implies a satellite detection probability of 4%. That figure is not too far from the Oklahoma detection probability of 3%. However there is a caveat for the Florida probability number. The lack of range of the ground stations compared to the satellite FOV means that we cannot obtain an average flash density for both the water regions and the land mass.

Correlation of Peak Optical Power with Peak Electric Field

From our ground truth pass of 8 August 1977 we were able to fit a power curve between the peak optical power as observed by the satellite sensor and the peak radiation electric field as measured on the ground. With the availability of the 1979 Oklahoma and Florida data bases, we wanted to test this relation to see if it agreed with the larger data bases. Figure 16 shows the data from Oklahoma and Florida with our empirical relation from 1977. There appears to be no correlation although the empirical line seems to be the boundary between the Florida data points and the Oklahoma data points. We suspect that if the satellite sensor observes the ground flashes directly the

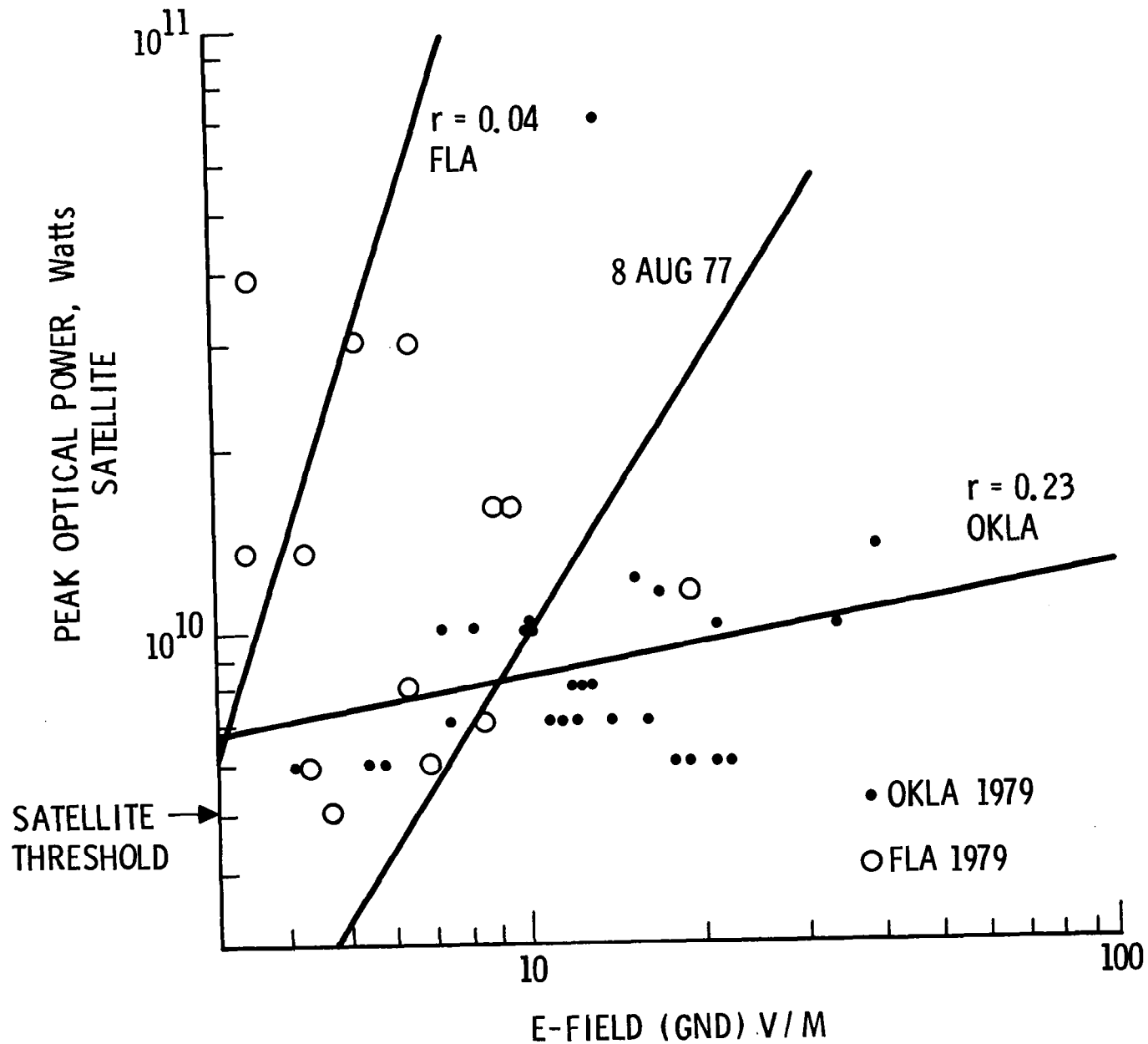


Figure 16. Peak E-Field versus Peak Optical Power for the Oklahoma-Florida Data Bases.

empirical relation probably is valid. But if the satellite observes the ground flash through a cloud or observes a cloud flash associated with the ground flash, there would not be a good correlation. The latter situation probably holds for Figure 16.

BOM Field Tests - Florida - Texas

During Spring 1979 the Bureau of Mines field tests of lightning location devices were located at San Antonio, Texas. We found two passes where the ground station and the satellite observed the same local storm. The baseline for the ground station for the BOM field tests was ~ 25 km which limited the range of detection somewhat. In one pass a very active squall line was near San Antonio, similar to the storm observed on 2 May 1979 in Oklahoma. In May-June 1979 the system was moved to Kennedy Space Center (KSC). We found one pass from that site in which the ground station and the satellite observed the same storm. One difficulty with the BOM tests was the infrequent operation of the system at the satellite pass times. During July-August at Socorro, NM, when the ground system was finally operating at maximum efficiency, there was no lightning activity around the ground site at 9 PM. Most of the lightning activity occurred at midday. The following table summarizes the results.

Texas - Florida 1979
BOM Field Tests

Date	# Gnd # Flashes	Satellite Triggers	% Triggers	# Sat. Triggers Correlation	No Correlation
10 Apr (Texas)	4		5	1/4 25%	4
21 Apr (Texas)	43		13	11/43 26%	2
26 Jun (Fla)	8		8	4/8 50%	4

It is remarkable that the correlation percentages are consistent with the other Oklahoma (25%) and Florida (>50%) correlations. There were no E-field data available for this data base.

False Correlation

Because of the 4 second resolution of the satellite data, there is a good probability of false correlation between the ground and satellite events. One way of evaluating the potential for false correlation is to treat the satellite and ground records as distinct records and to examine the joint probability as calculated from the ratio of filled 4 sec. bins to the total number of bins. So if we define

$$P_{\text{GND}} = \frac{\# \text{ of bins with events}}{\text{total } \# \text{ of bins}} \text{ (Ground),}$$

$$P_{\text{sat}} = \frac{\# \text{ of bins with events}}{\text{total } \# \text{ of bins}} \text{ (Satellite),}$$

$$P_{\text{joint}} = P_{\text{GND}} \bullet P_{\text{SAT}},$$

the joint probability will give a measure of a purely random correlation between the two records.

The following table gives the probability of a false correlation for each of the records examined.

False Correlation Evaluation

Record	$P_{\text{joint}}\%$	Correlation %
9 April (Okla)	5%	50
10 April	11	22
1 May	15	25

2 May	49	26
14 July (Fla.)	2%	33
18 July	1	100
19 July	3	83
5 Aug	8	50
15 Aug	1	50
16 Aug	2	100
10 Apr (Tx.)	2	25
21 Apr (Tx.)	20	26
26 June (Fla)	7	50

The Oklahoma data shows a high probability for false correlation because of the high ground occurrence rate. The Florida data set conversely shows a lower false correlation probability with generally higher correlation percentages than found on the Oklahoma data set.

At this time we can not evaluate the false correlation problem to any greater detail. However it is significant that the joint probability varies widely for the Oklahoma data while the correlation percentage remains fairly stationary for the latter three dates. The Florida data set, on the basis of this analysis, has the highest confidence level because of the low joint probability percentages.

General Correlation Between Ground and Satellite

As a final comparison between the ground and satellite records, we did a regression analysis between the number of events observed on the ground versus the number of events observed on the satellite. This general correlation would be the type done on any future operational lightning sensor used in forecasting. Figure 17 shows the correlation between the ground and satellite records for 13 passes. A correlation coefficient of 0.6 is obtained which is significant.

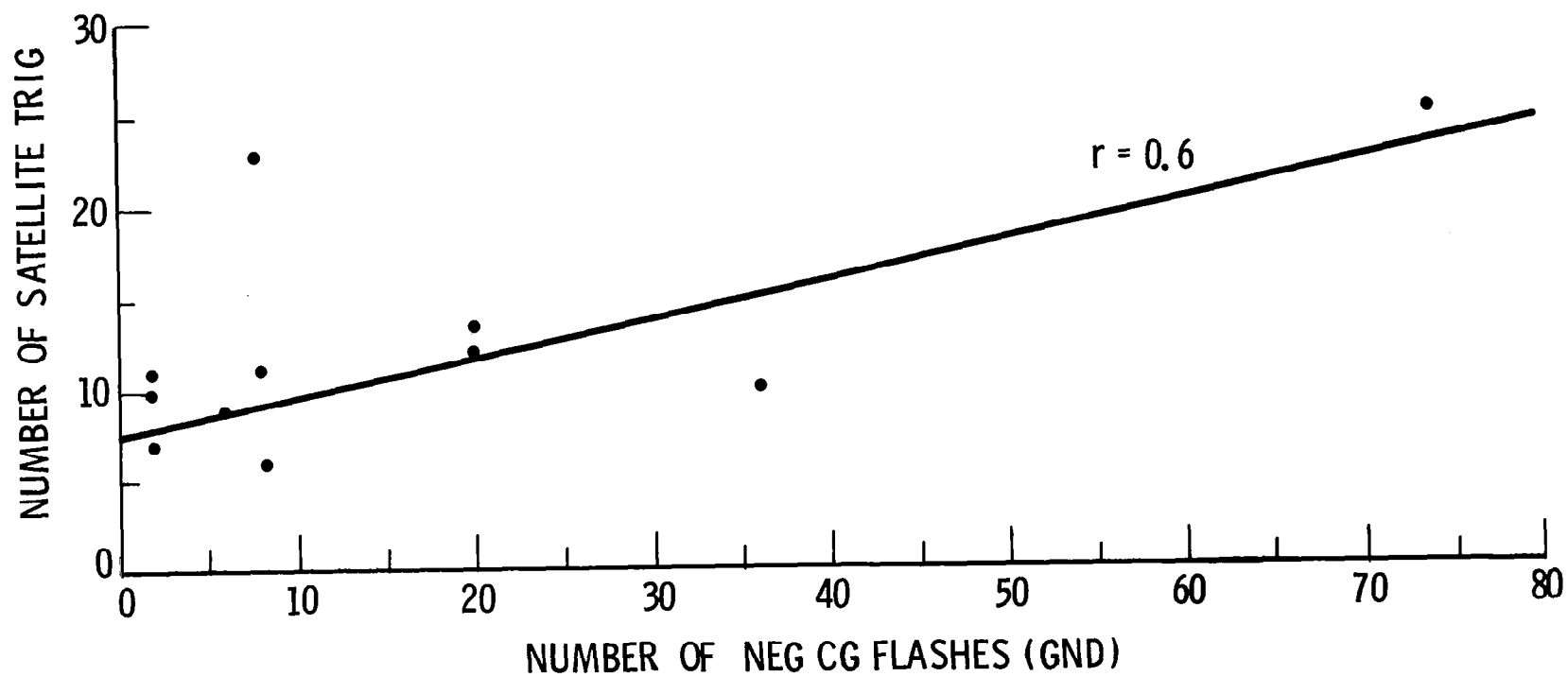


Figure 17. General Correlation between Satellite and Ground Occurrence Rates

Summary and Conclusions

1. For the Spring severe storm season in Oklahoma and Texas the satellite lightning sensor saw triggers that correlated in time with ~25% of the negative return flashes.
2. For the summer lightning season in Florida, the sensor saw triggers that correlated in time with 50% or more of the negative return flashes.
3. Comparison of the satellite flash densities in both Oklahoma and Florida with the measured flash density gives a total detection probability for the satellite sensor of 3-4%.
4. There appears to be no general correlation between duration of satellite events and the polarity of the flash as determined by the ground station. However for individual satellite passes a correlation may appear.
5. There appears to be no general correlation between peak optical power as observed by the satellite and the peak radiation E-field as observed by the ground station.
6. The satellite detector generally observes significant occurrence rates when passing over severe storm regions, but the observed rate is also a function of cloud attenuation and viewing angles from the satellite.
7. The results of the ground truth tests were limited by the 2-3 minute satellite observation sensor period over any particular storm and by the 4 second integration time. The timing uncertainty appears to be the greatest limitation to the interpretation of the results.

Recommendations for Future Work

Mike Maier operated a lightning location network in South Florida in summer 1980 and gathered a very good data base which could be correlated with the PBE-3 data base that has msec. timing resolution. The latter is still

being processed by AFTAC. It will probably be available in 1982.

The PBE-3 instrument is still being operated by the Air Force and tapes are still being sent to AFTAC. However the tapes are recycled after several months. Hopefully the satellite will still be operational in spring 1982 when the Severe Storms lab in Norman, Oklahoma will operate its four station lightning location system. It will have the capability to detect both positive and negative flashes which will help reduce the uncertainties in ground truth correlations. The satellite data would be processed by AFTAC on a courtesy basis.